
THE TRACKING TAG WILL RECORD THE SHARK'S MOVEMENT AND HABITS.
THEN, IT WILL POP FREE AND FLOAT TO THE SURFACE.
WE CAN'T AFFORD A RECOVERY PROGRAM, SO THE CAPSULES WILL INFLATE HELIUM BALLOONS, DRIFT OVER LAND,
AND HOPEFULLY BE FOUND AND MAILED TO US. ANY QUESTIONS?
IF FOUND PLEASE CALL
CHUNK
SPLOOSH
!!!
CLICK
HISSSS
??
AAAAAAAA
CHOMP CHOMP
DADDY?
YES?
I WANT TO BE A SCIENTIST.

xkcd.com/585

Ecological Forecasts: An Emerging Imperative

James S. Clark,[1*] Steven R. Carpenter,[2] Mary Barber,[3] Scott Collins,[4] Andy Dobson,[5] Jonathan A. Foley,[6] David M. Lodge,[7] Mercedes Pascual,[8] Roger Pielke Jr.,[9] William Pizer,[10] Cathy Pringle,[11] Walter V. Reid,[12] Kenneth A. Rose,[13] Osvaldo Sala,[14] William H. Schlesinger,[15] Diana H. Wall,[16] David Wear[17]

Science 2001

"THE PROCESS OF PREDICTING THE STATE OF ECOSYSTEMS, ECOSYSTEM SERVICES, AND NATURAL CAPITAL, WITH FULLY SPECIFIED UNCERTAINTIES, AND IS CONTINGENT ON EXPLICIT SCENARIOS FOR CLIMATE, LAND USE, HUMAN POPULATION, TECHNOLOGIES, AND ECONOMIC ACTIVITY"

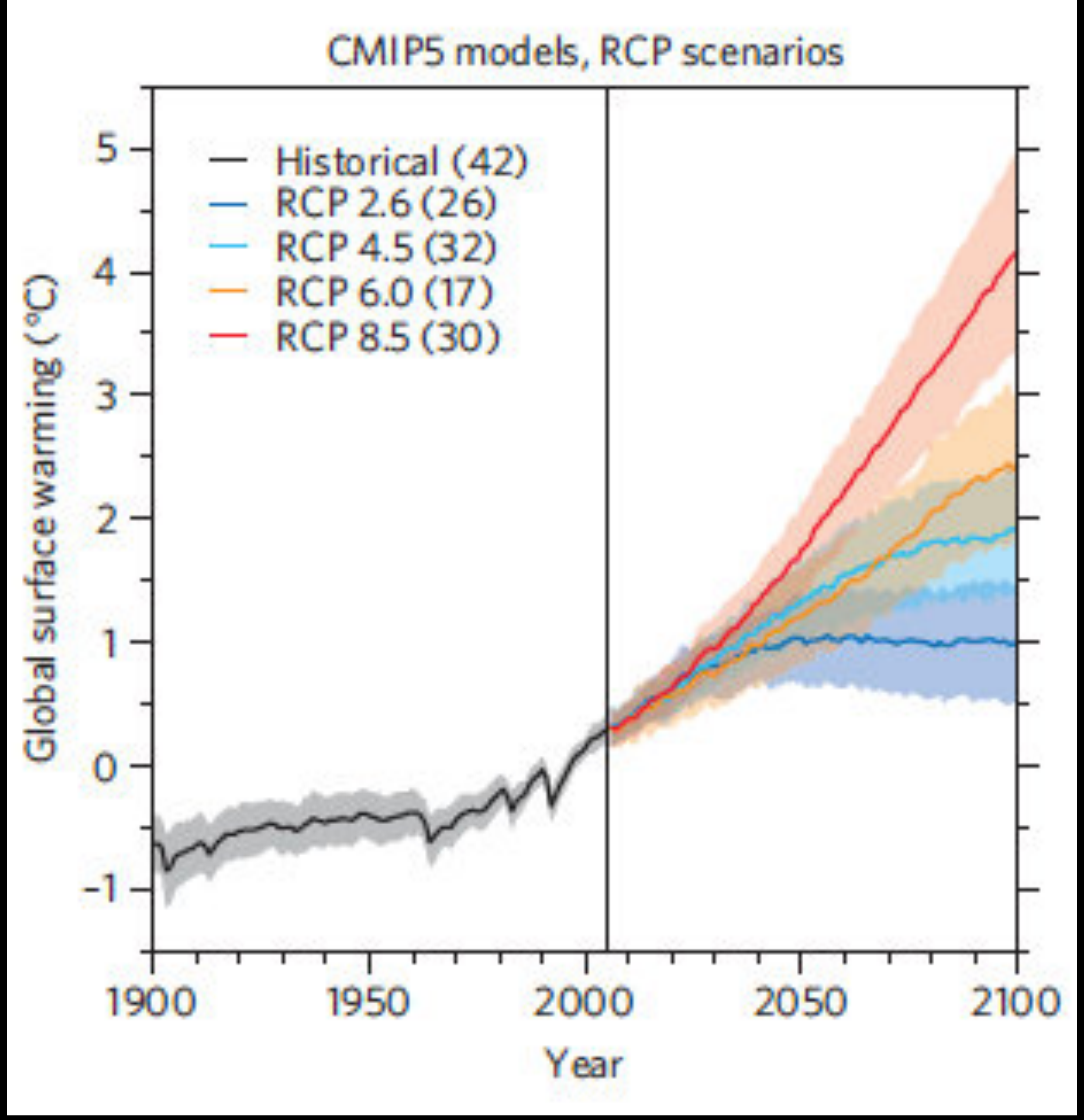

Syntax is field-dependent & terms are used interchangeably.
Forecast
Predict
Projection
The use of common forecasting terminology is increasing.
Scientific literature
Google trends
The frequency of terms varies by field.
Mathematics
Economics & finance
Ag. & biological sciences
% of papers
Terms are often used interchangeably, which creates confusion.
Synonymous usage with other terms
Forecasting end goals and products are highly variable.
Decision support
Theory advancement
System understanding
Methods development
Generating forecast
System understanding
Predictive modeling
Quantifying uncertainty
So, what is a forecast?
A prediction and its associated uncertainty...
... about an out-of-sample state of a system...
Time
Space
Context
... made by combining models and data.
Unified terminology in ecoforecasting is crucial for improving communication, collaboration, and application across scientific, social, and policy-making domains amidst rapid environmental change.
Sjodin, Stokes, et al. in review

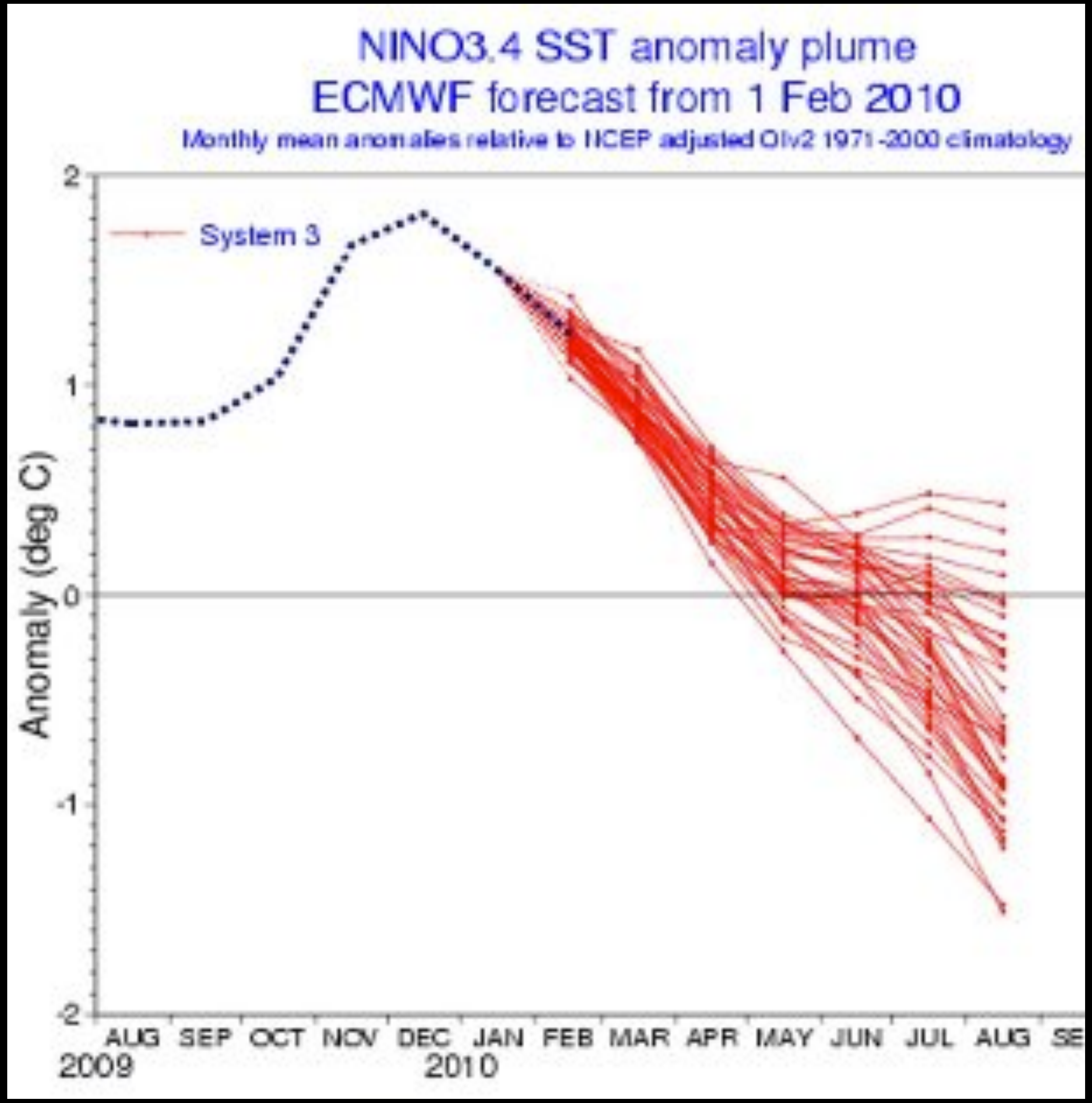
PROJECTION

PREDICTION

"PROBABILISTIC STATEMENT THAT IT IS POSSIBLE THAT SOMETHING WILL HAPPEN IN THE FUTURE" GIVEN BOUNDARY CONDITION SCENARIOS

"PROBABILISTIC STATEMENT THAT SOMETHING WILL HAPPEN IN THE FUTURE BASED ON WHAT IS KNOWN TODAY"





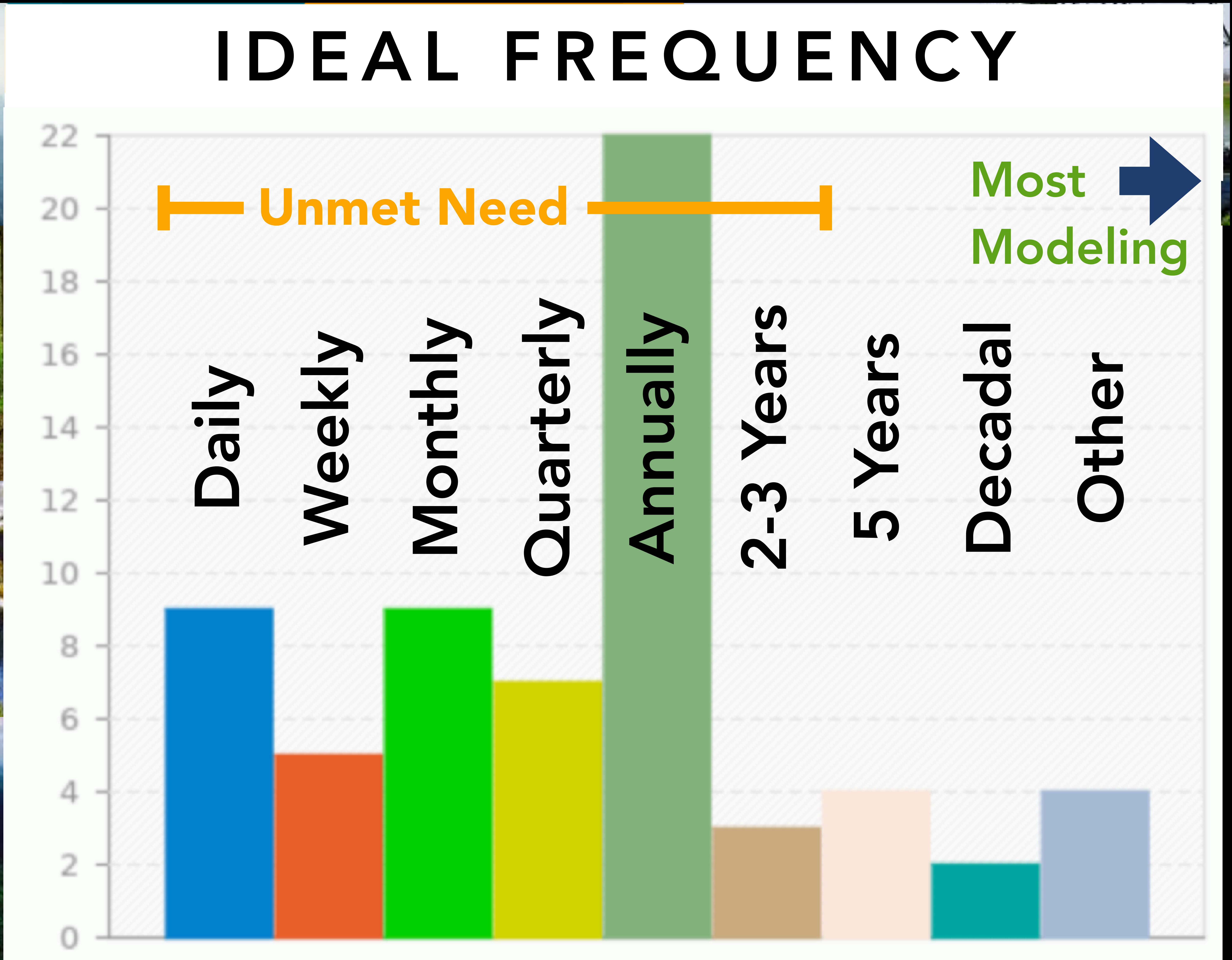
MacCracken 2001

WHY FORECAST?

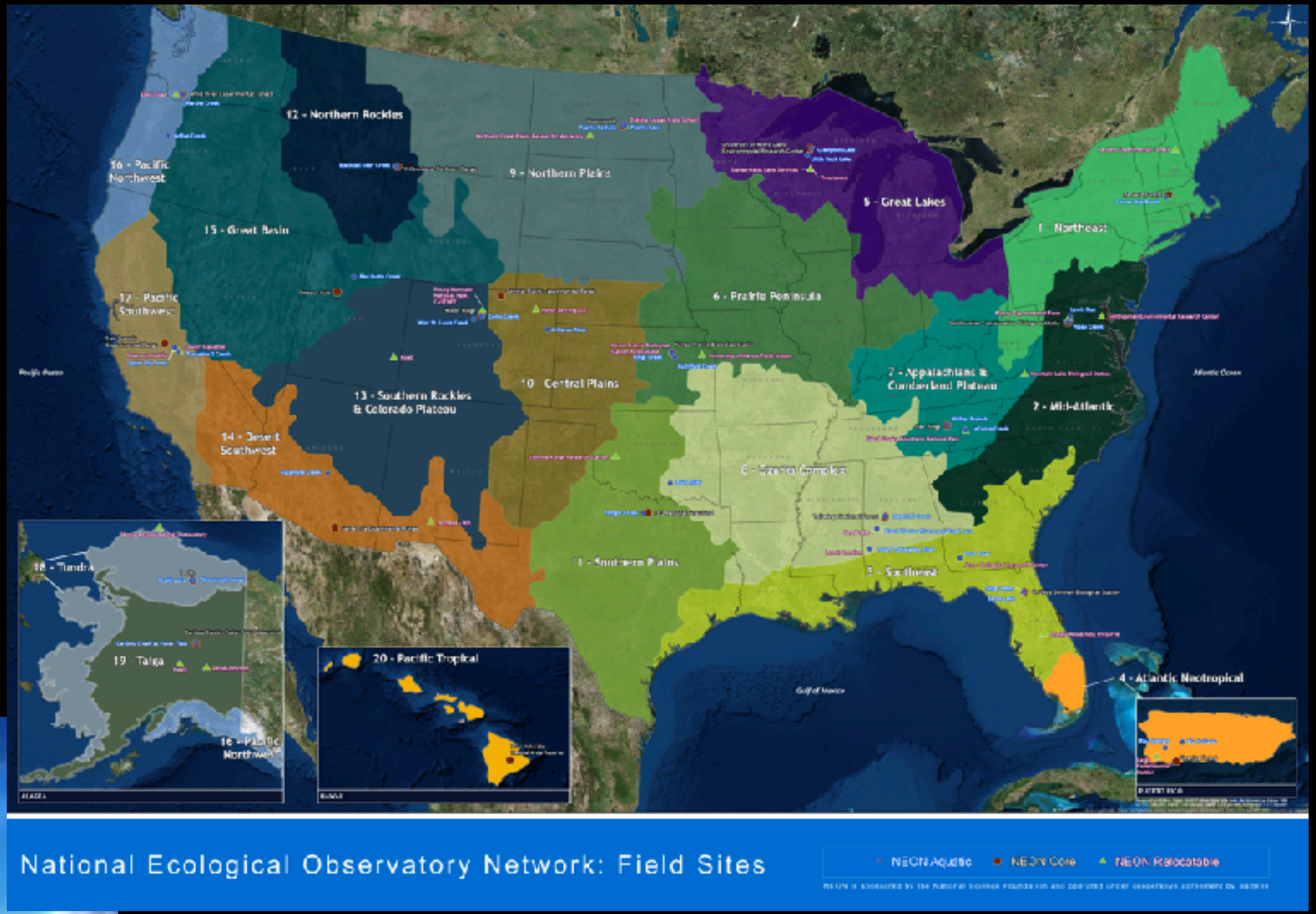

CLIMATE CHANGE
Stationarity Is Dead:
Whither Water Management?
Environmental
P. C. D. Milly,1* Julio Betancourt,2 Malin Falkenmark,3 Robert M. Hirsch,4 Zbigniew W. Kundzewicz,5 Dennis P. Lettenmaier,6 Ronald J. Stouffer7
Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.
Science 2008
DECISIONS ARE ABOUT THE FUTURE

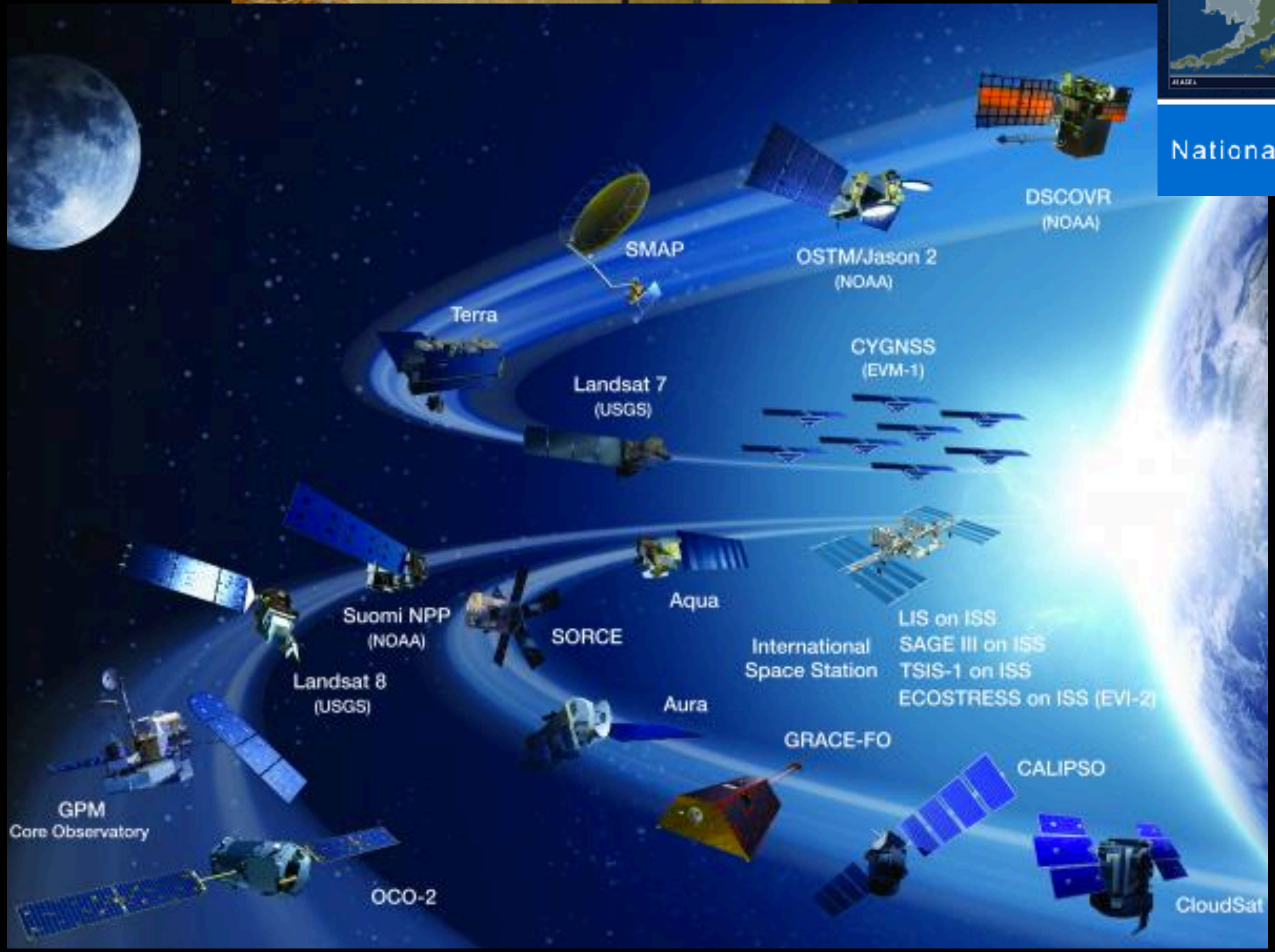
NASA Carbon Monitoring **Stakeholder** Survey

data courtesy Edil Sepulveda Carlo



REAL TIME SCIENCE





USA npn National Phenology Network
Taking the Pulse of Our Planet

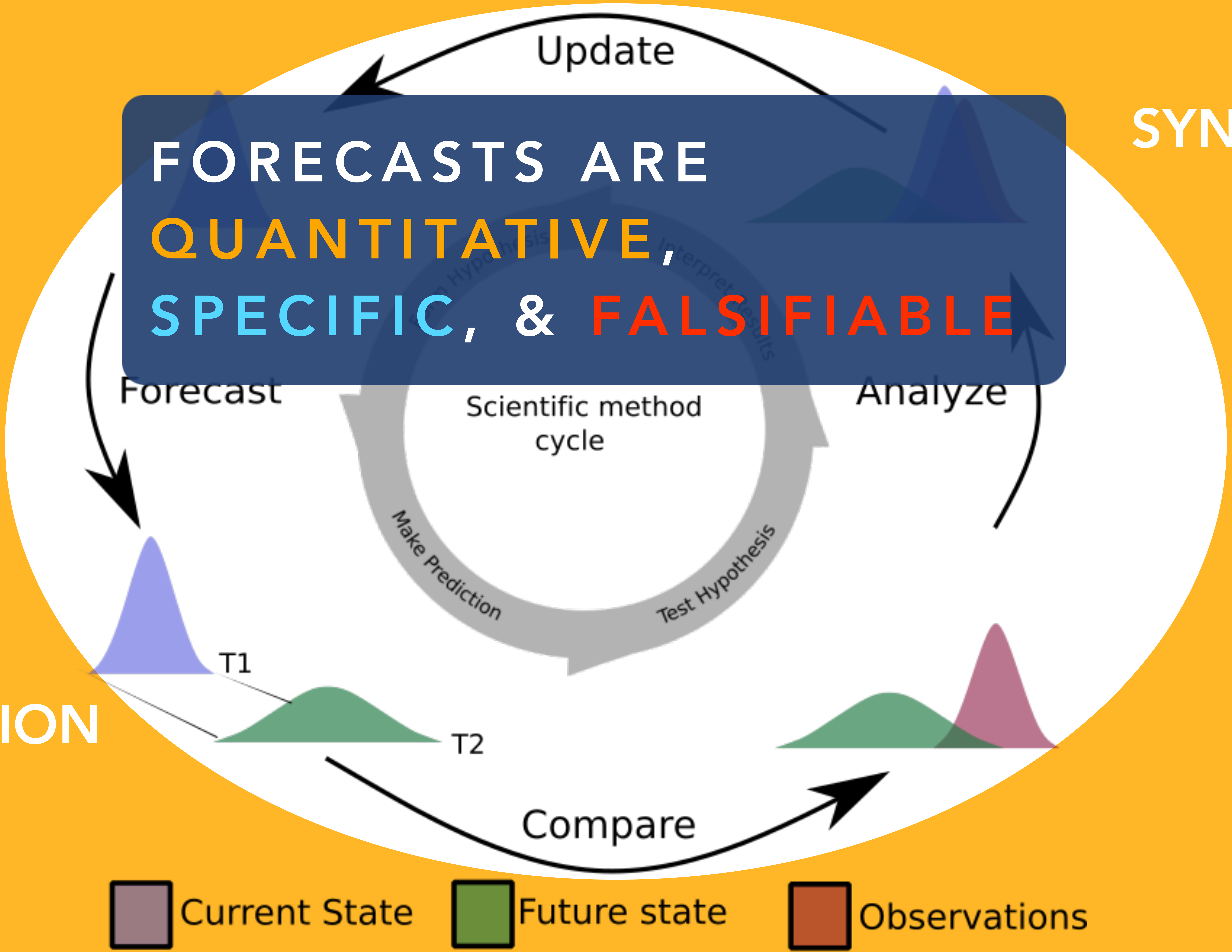
iNaturalist
Explore Learn Record

eBird

GLOBAL SOUNDSCAPES

FORECASTS ARE QUANTITATIVE, SPECIFIC, & FALSIFIABLE

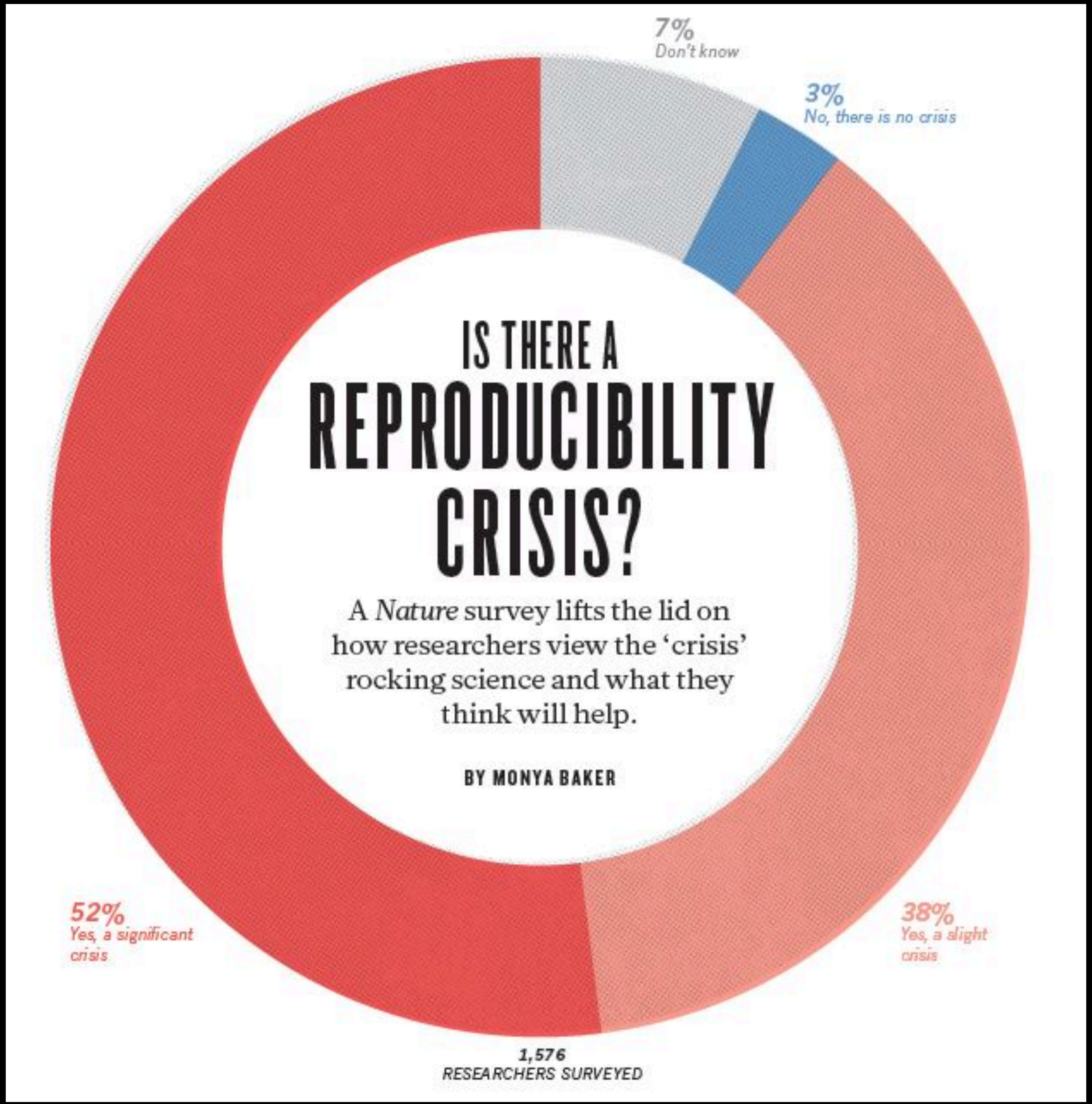
SYNTHESIS



PREDICTION

Figure: T. McCabe
Dietze et al 2018 PNAS

Forecasts are a priori

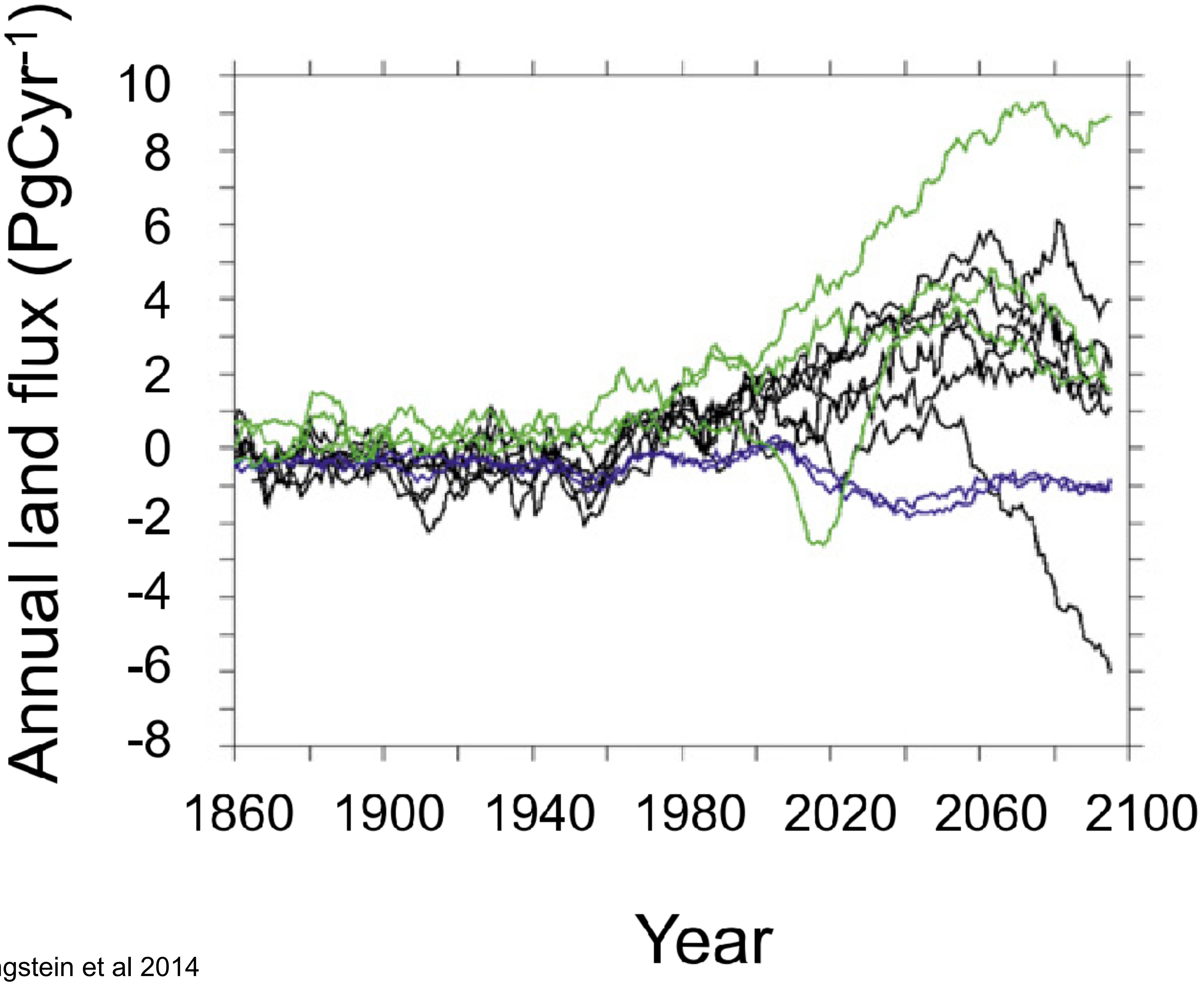


and out-of-sample

FORECASTS SYNTHESIZE

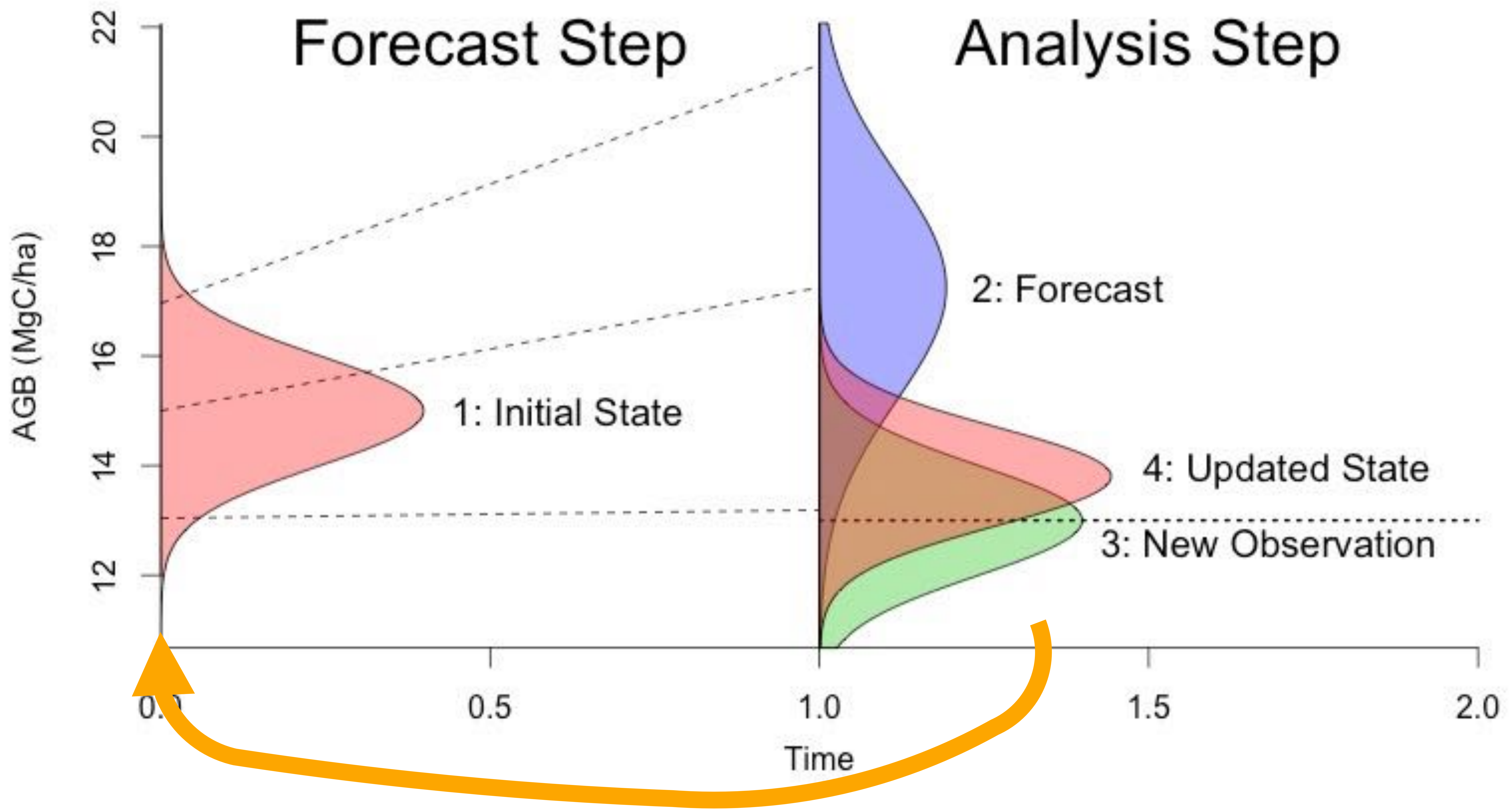
N FERTILIZATION

- Previous knowledge: +25% +/- 5%
- +50% vs +25% indistinguishable under NULL
- 0% “non-significant”



Friedlingstein et al 2014

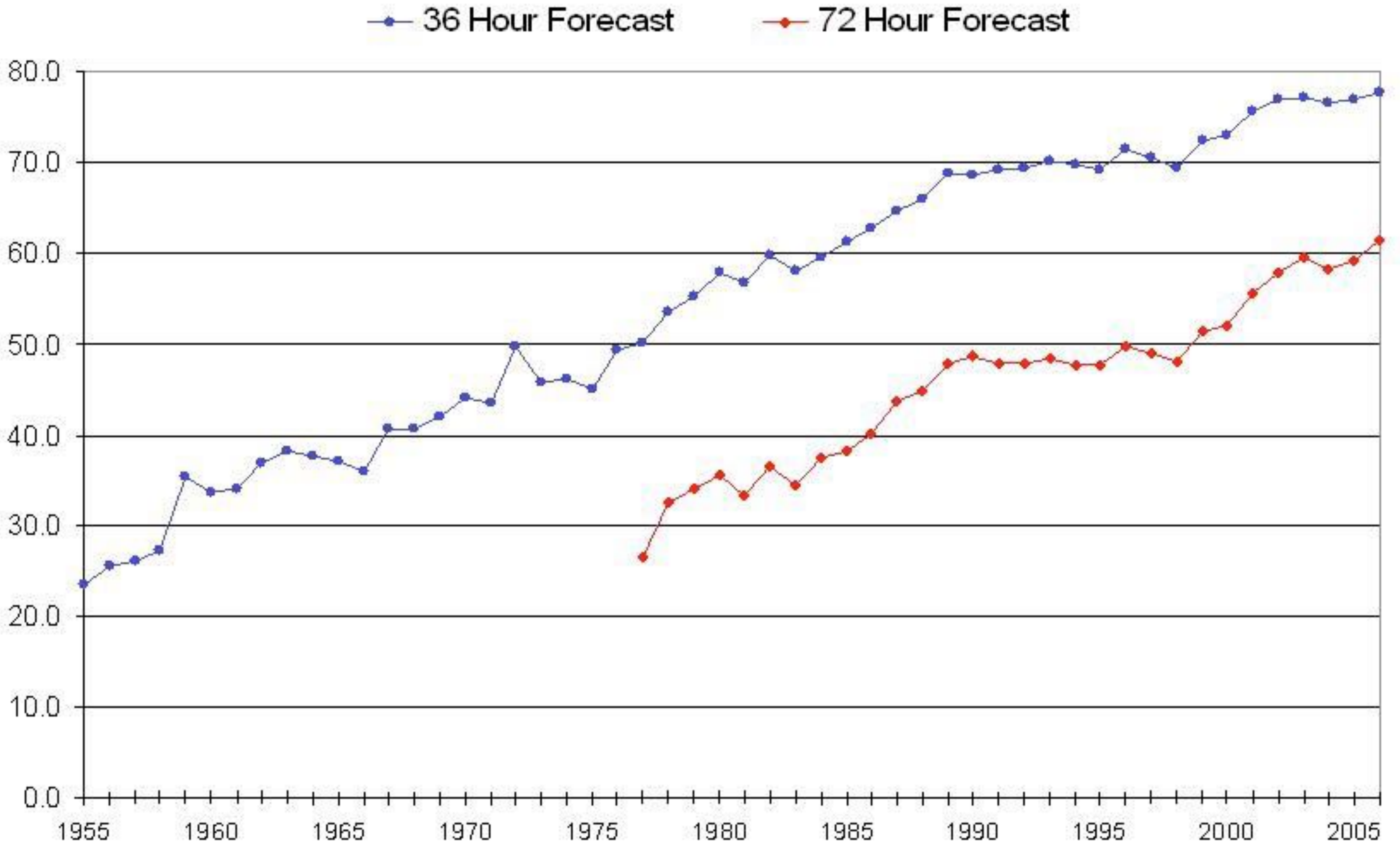
Improvement requires feedback



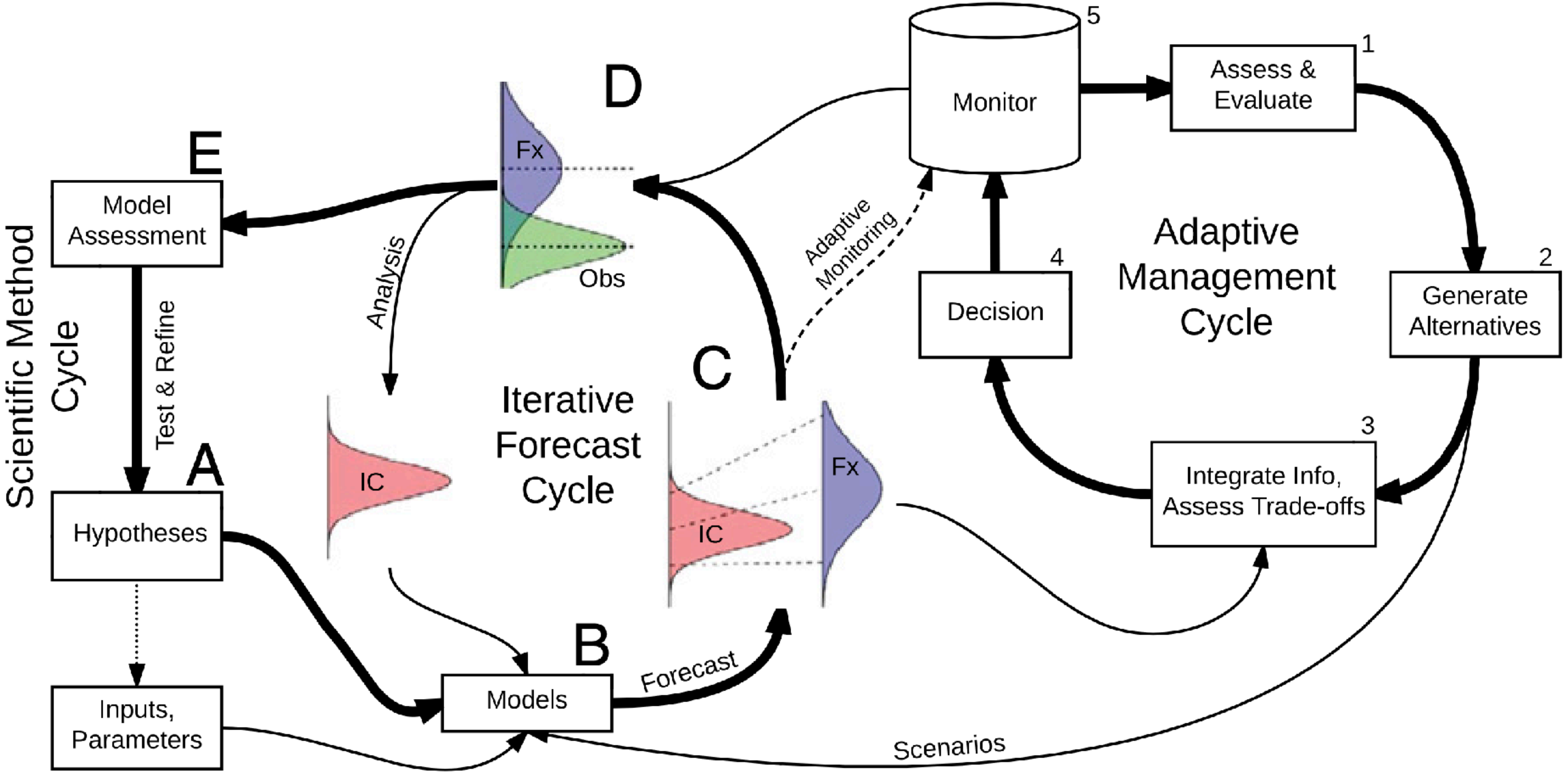
NCEP Operational Forecast Skill

36 and 72 Hour Forecasts @ 500 MB over North America

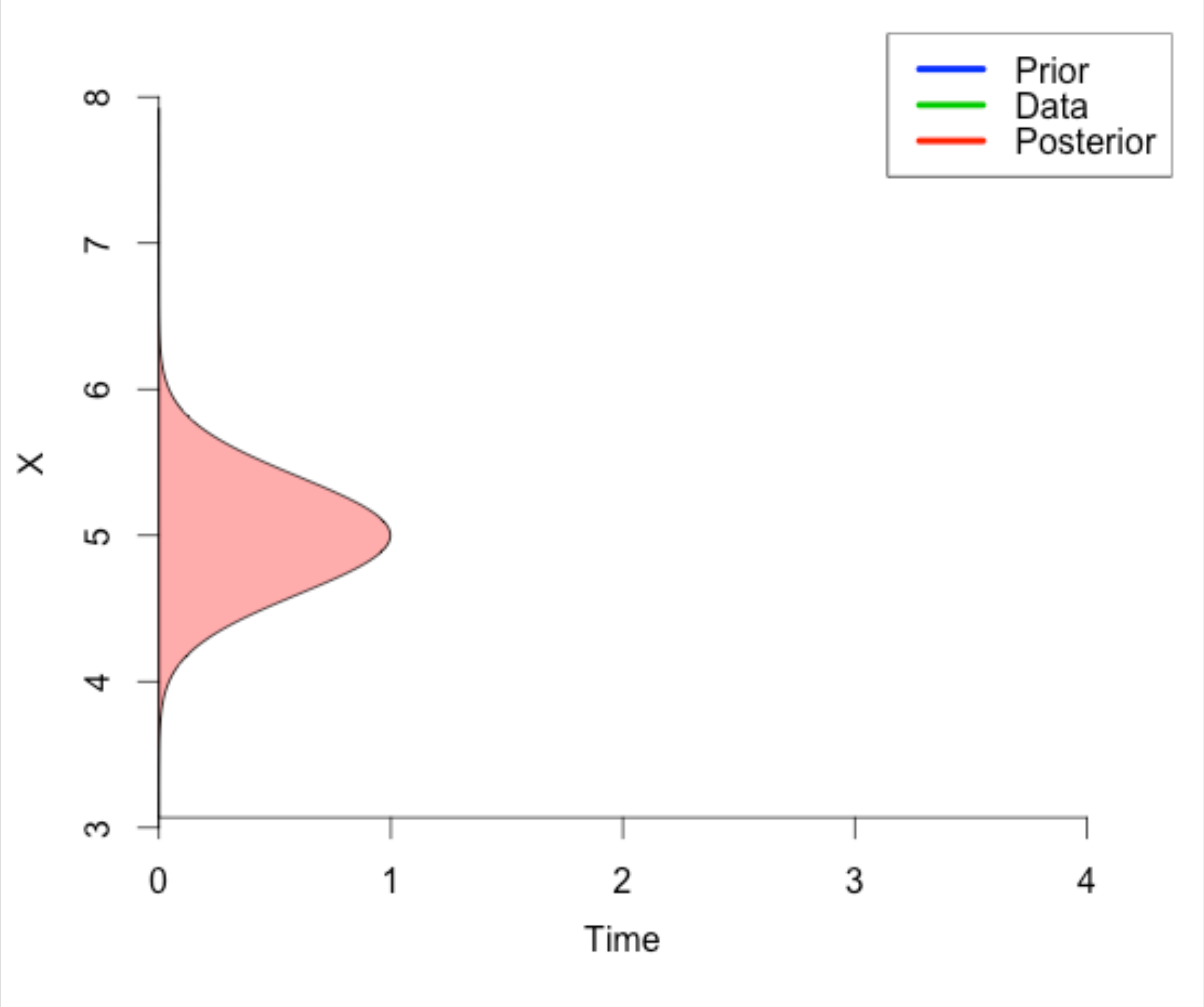
[100 * (1-S1/70) Method]



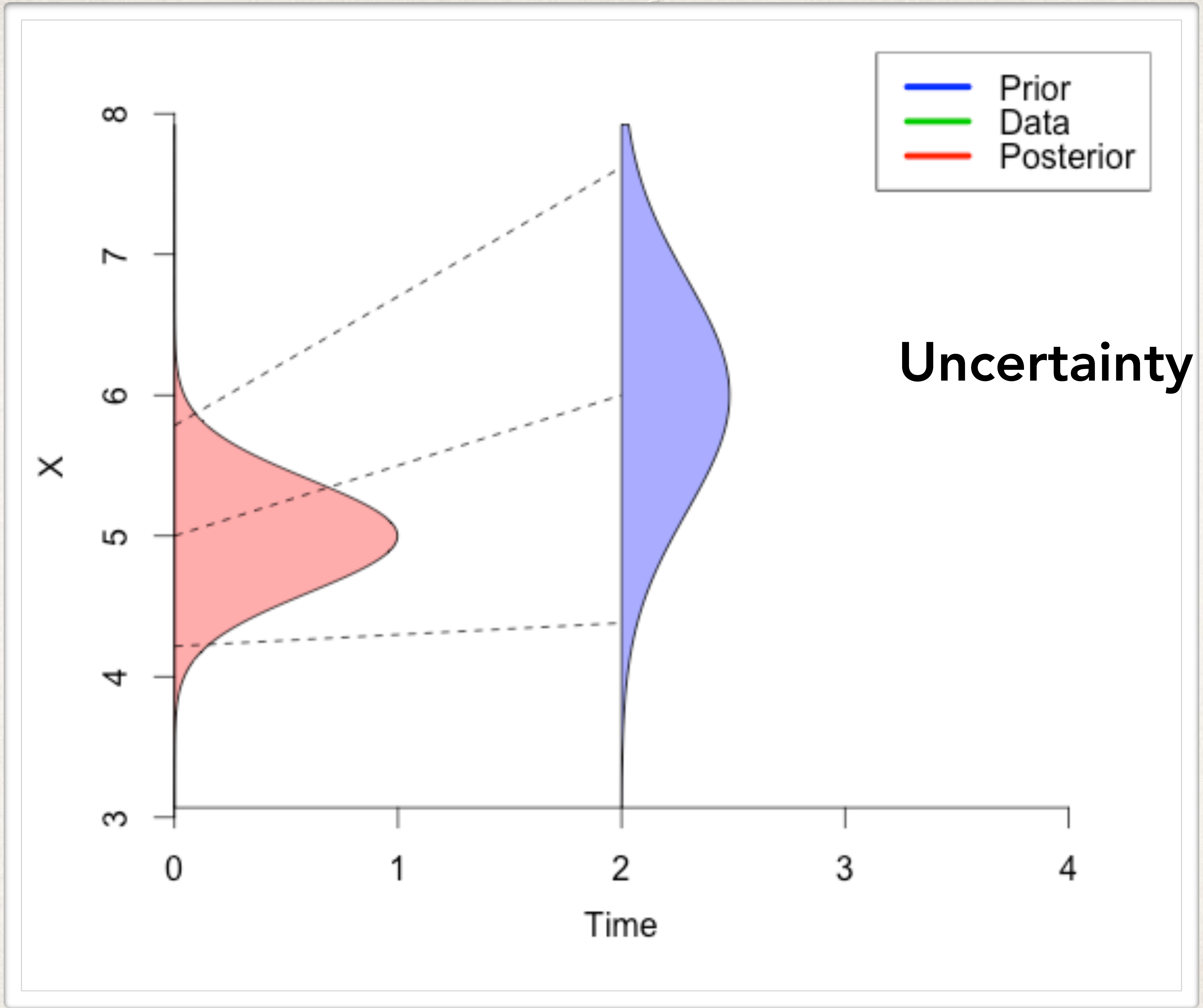
NCEP Central Operations January 2007



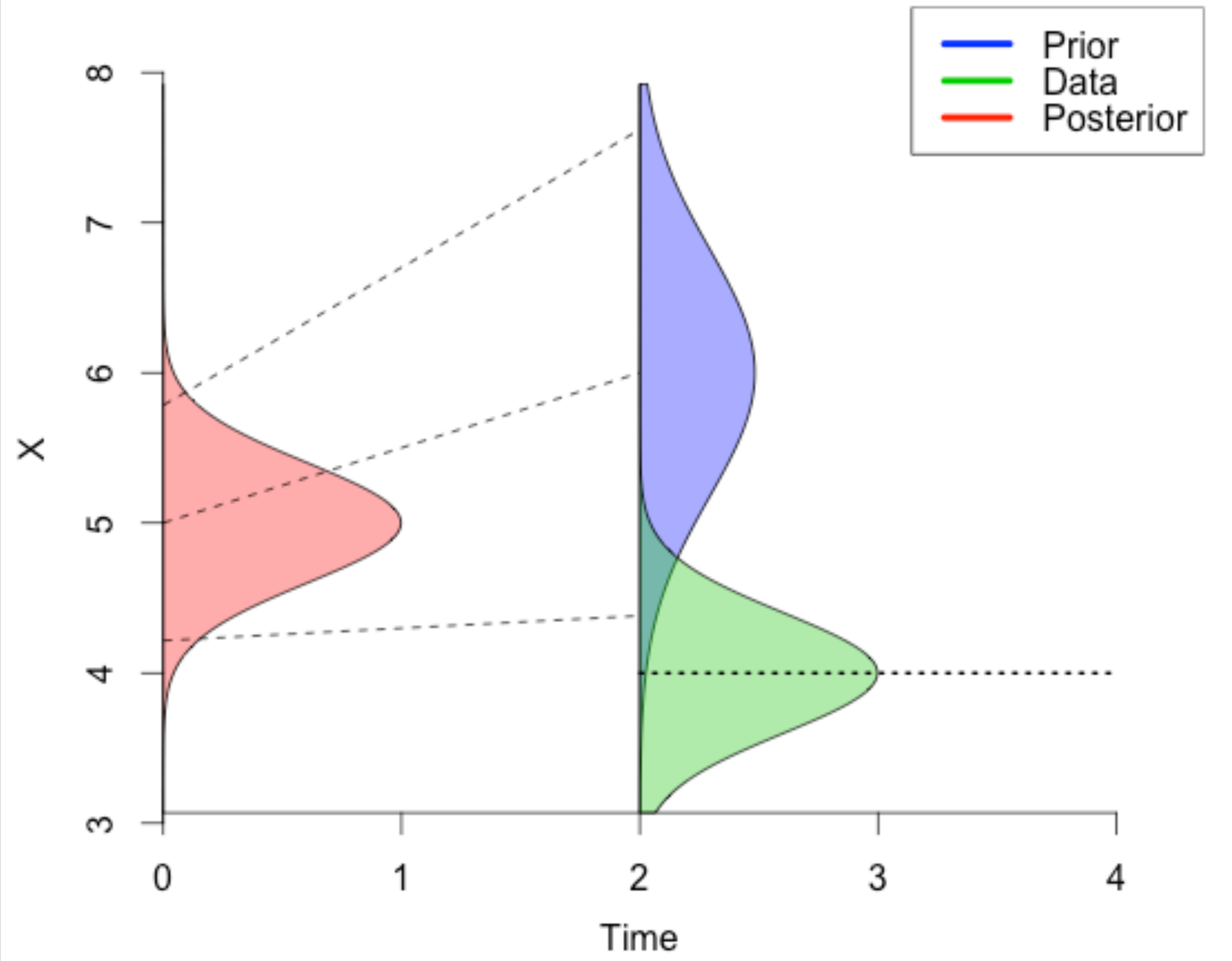
Dietze et al 2018 PNAS https://doi.org/10.1073/pnas.1710231115



Prior
Data
Posterior
X
8
7
6
5
4
3
0
1
2
3
4
Time



Uncertainty Propagation



Prior
Data
Posterior
X
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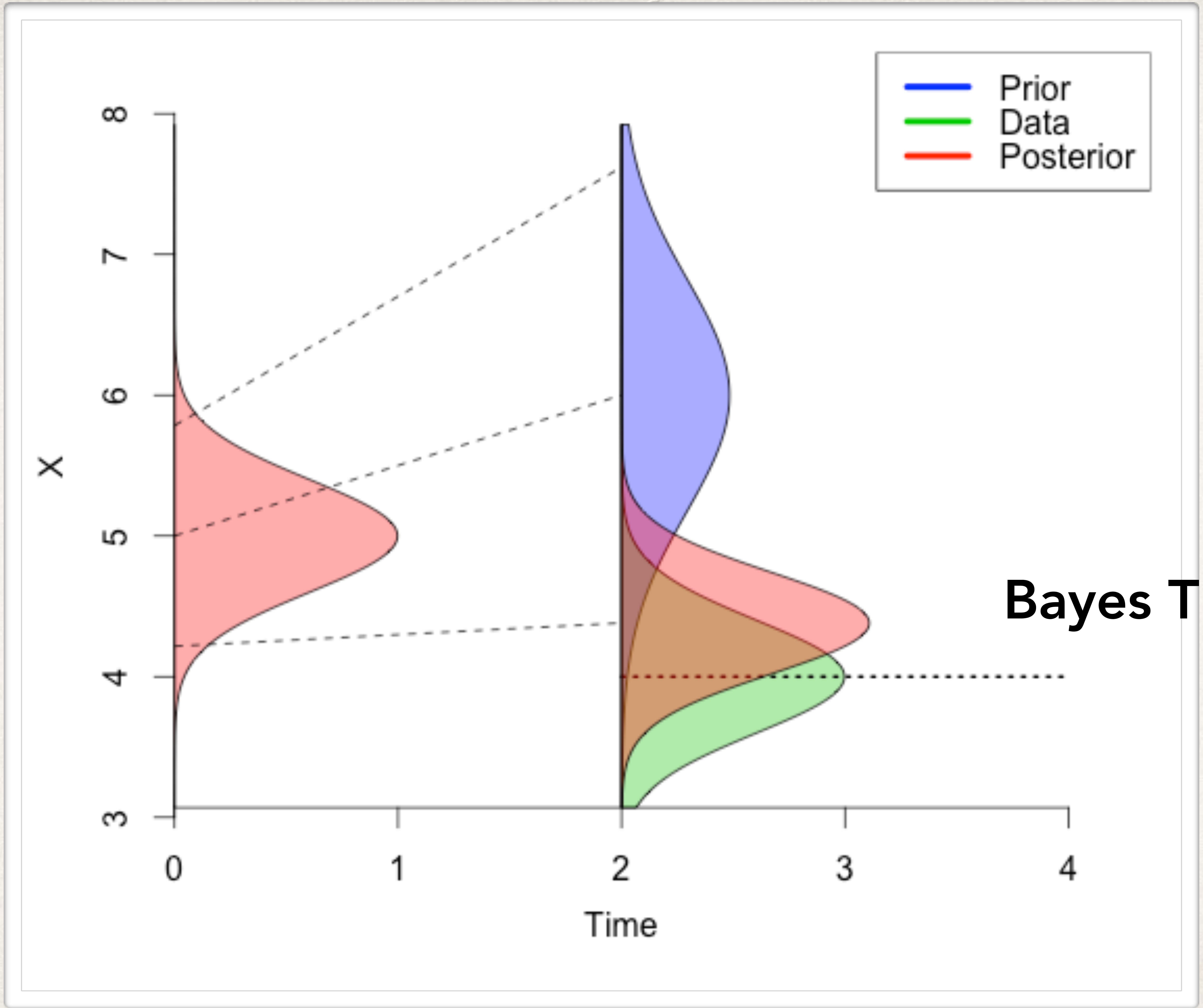
Time

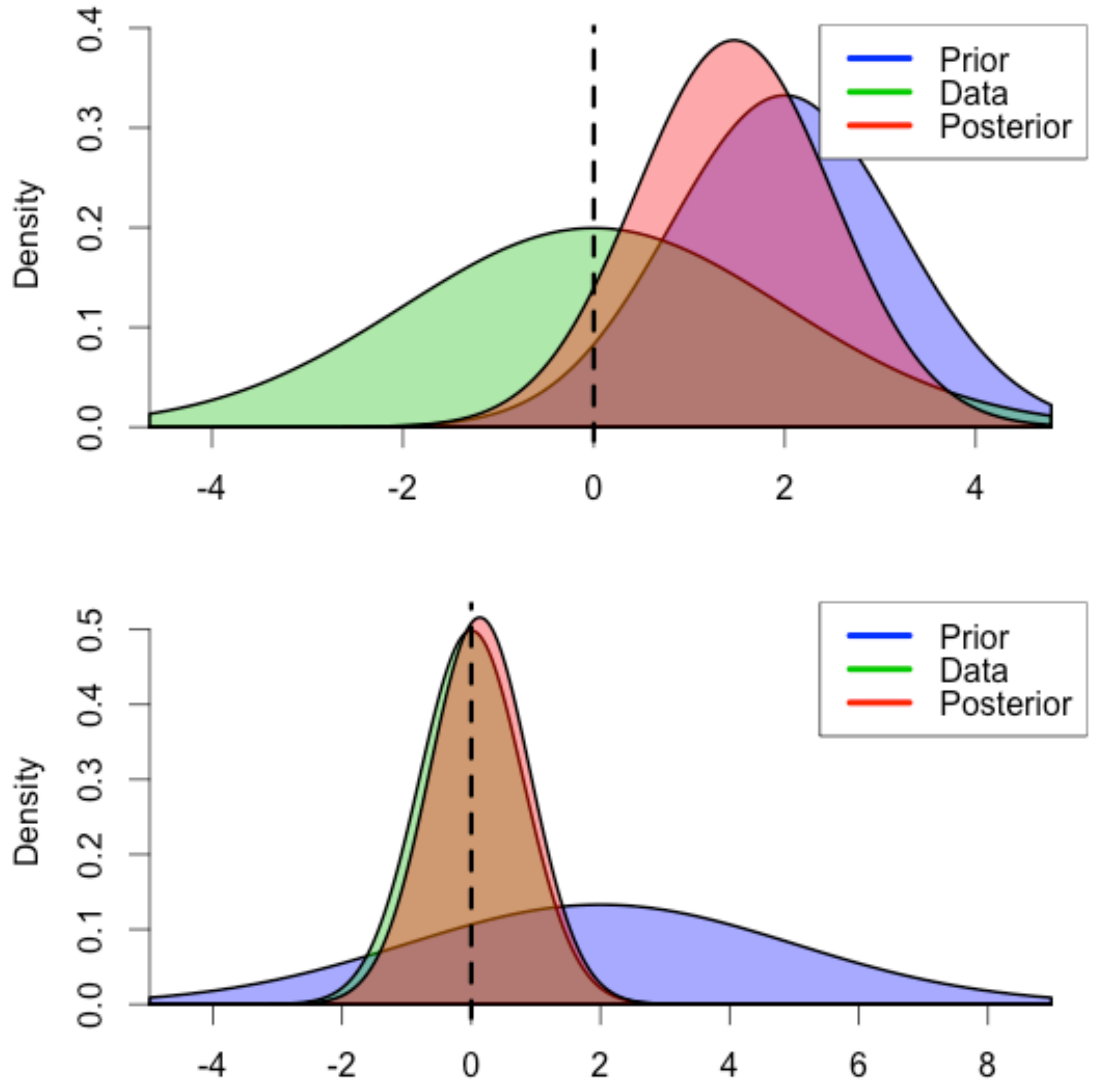


Bayes Theorem

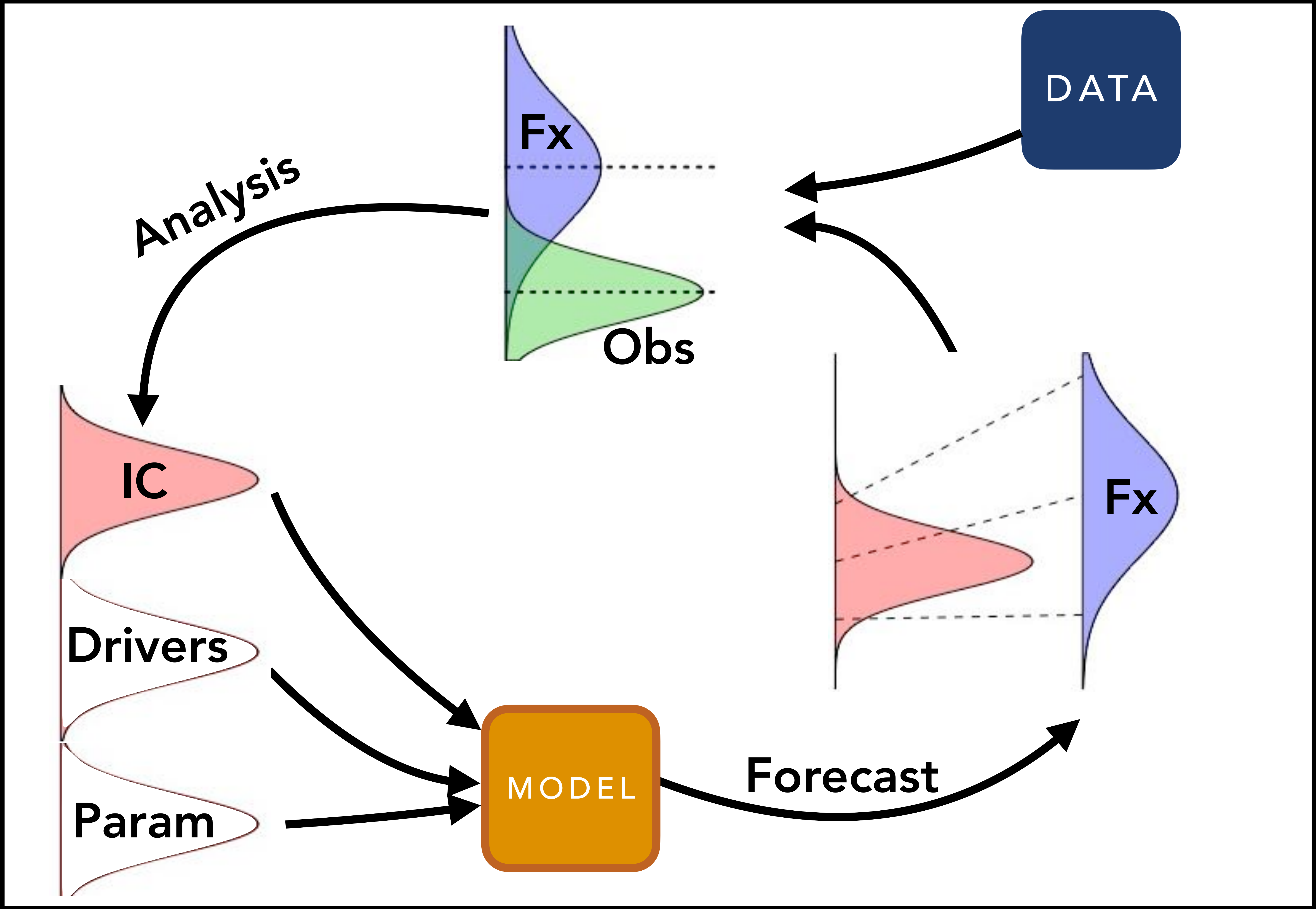
BAYES THEOREM

Posterior — Likelihood — Prior

$$P(\theta|y) = \frac{P(y|\theta)\,P(\theta)}{\int_{-\infty}^{\infty} P(y|\theta)\,P(\theta)\,d\theta}$$



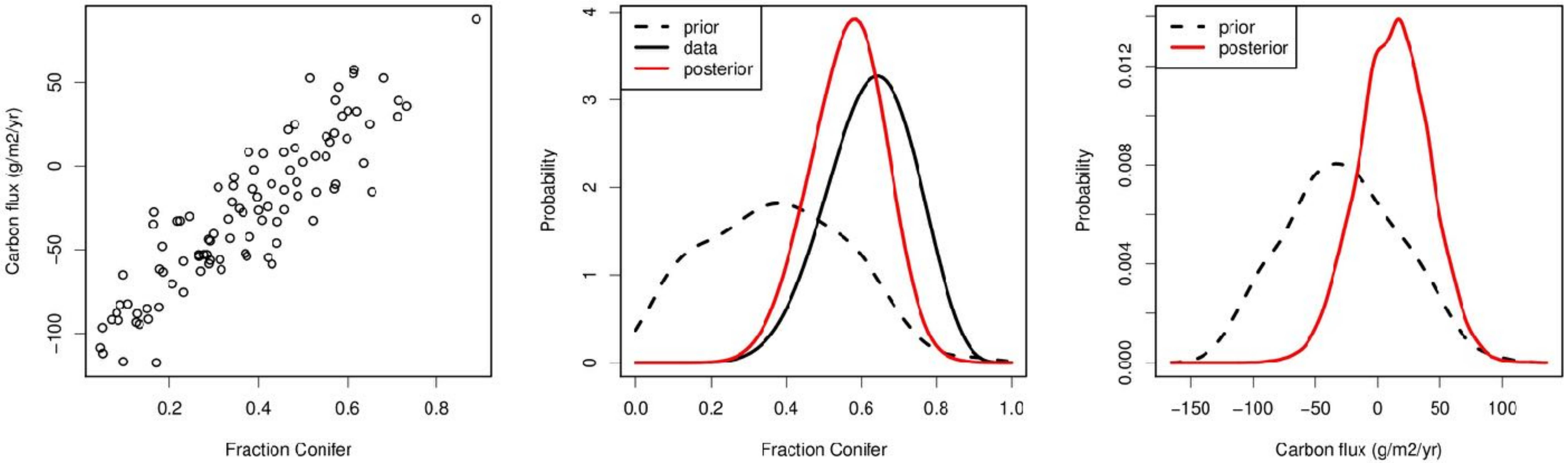
- Returns full probability distribution (uncertainty)
- Inherently iterative
- Handle's complexity of the real world
- Capture's prior knowledge



Forecasts should be updated when new data becomes available

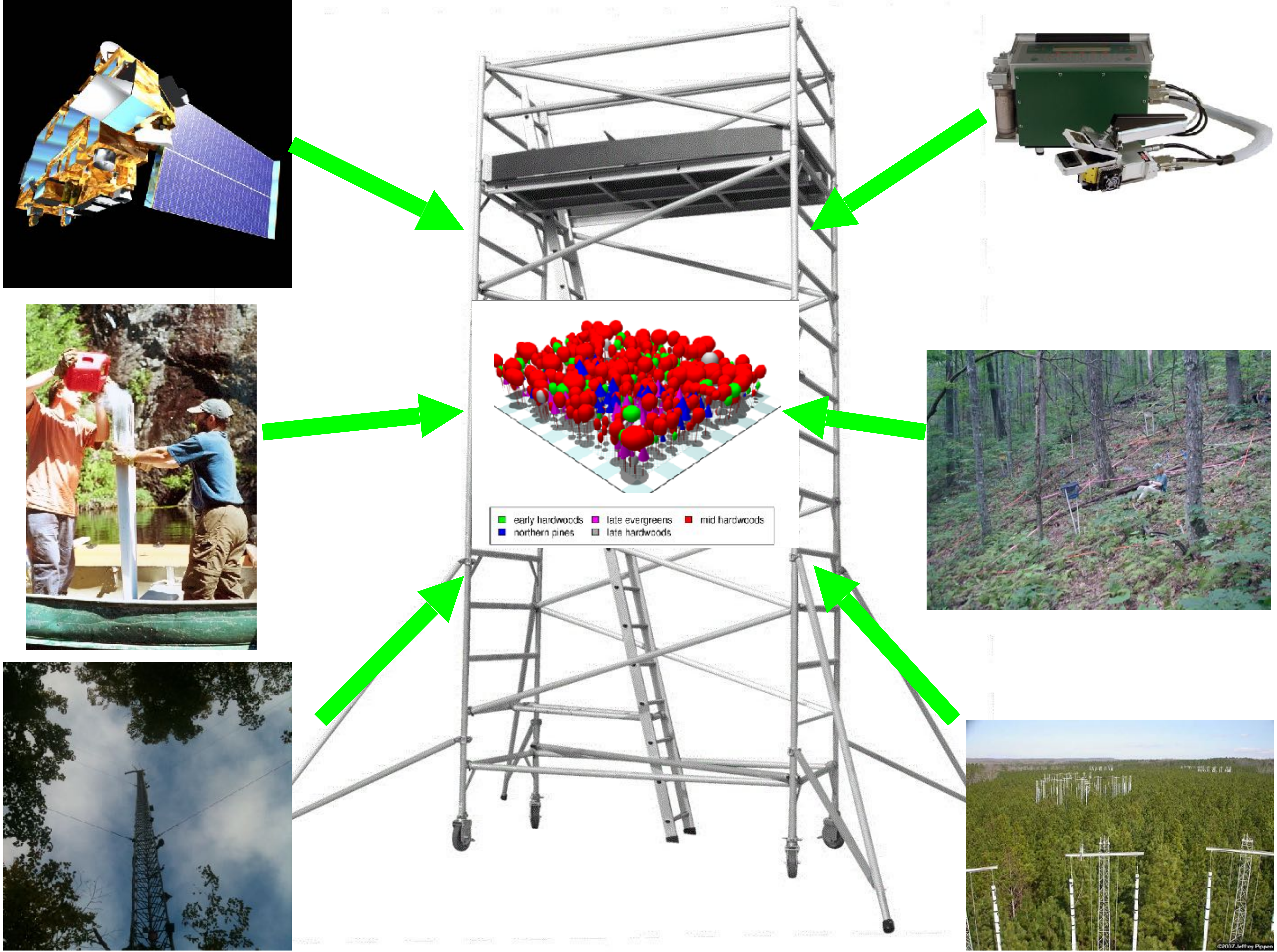
$$P(\theta|y) \propto P(y|\theta)\,P(\theta)$$

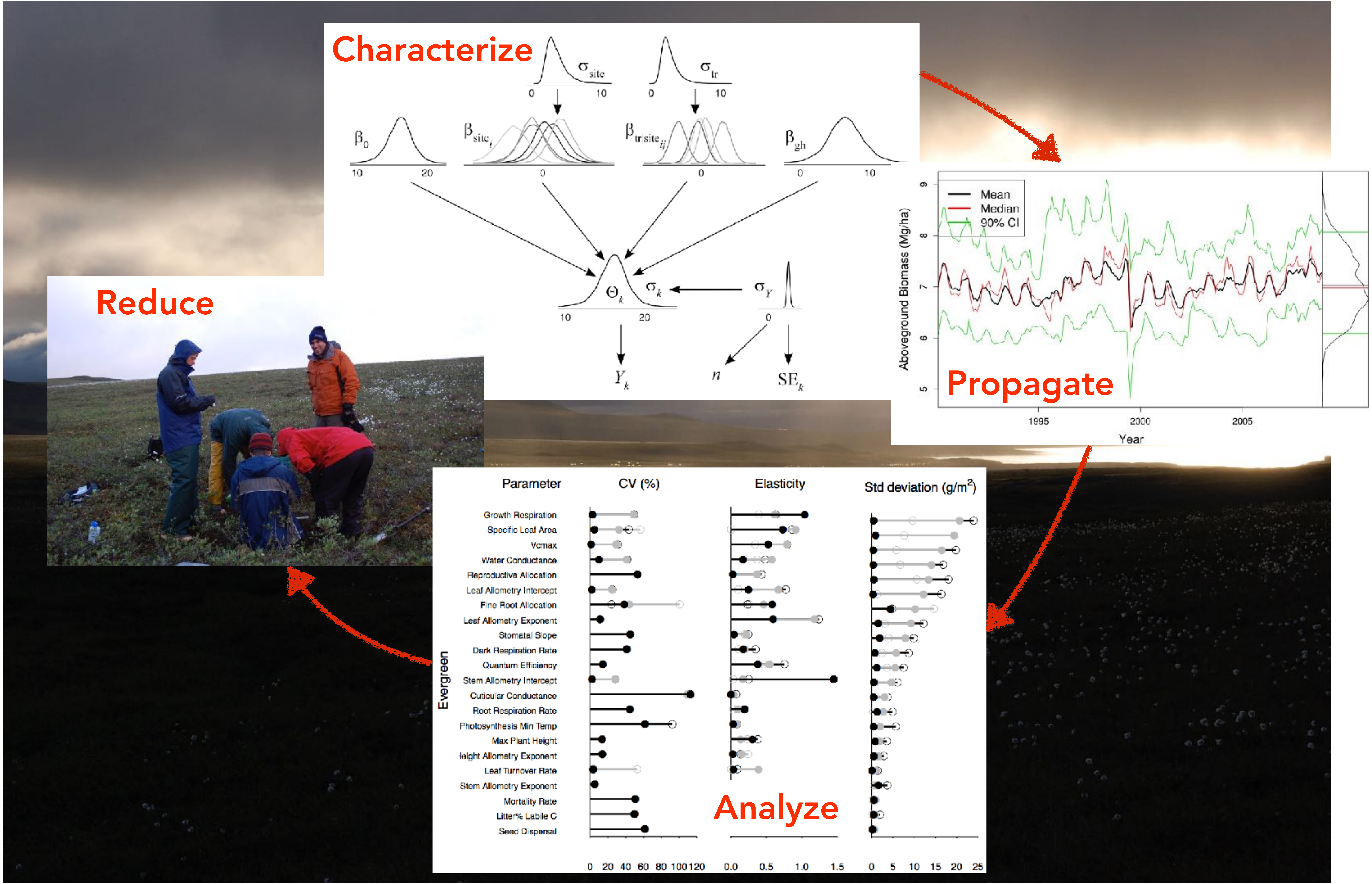
State-Variable Data Assimilation



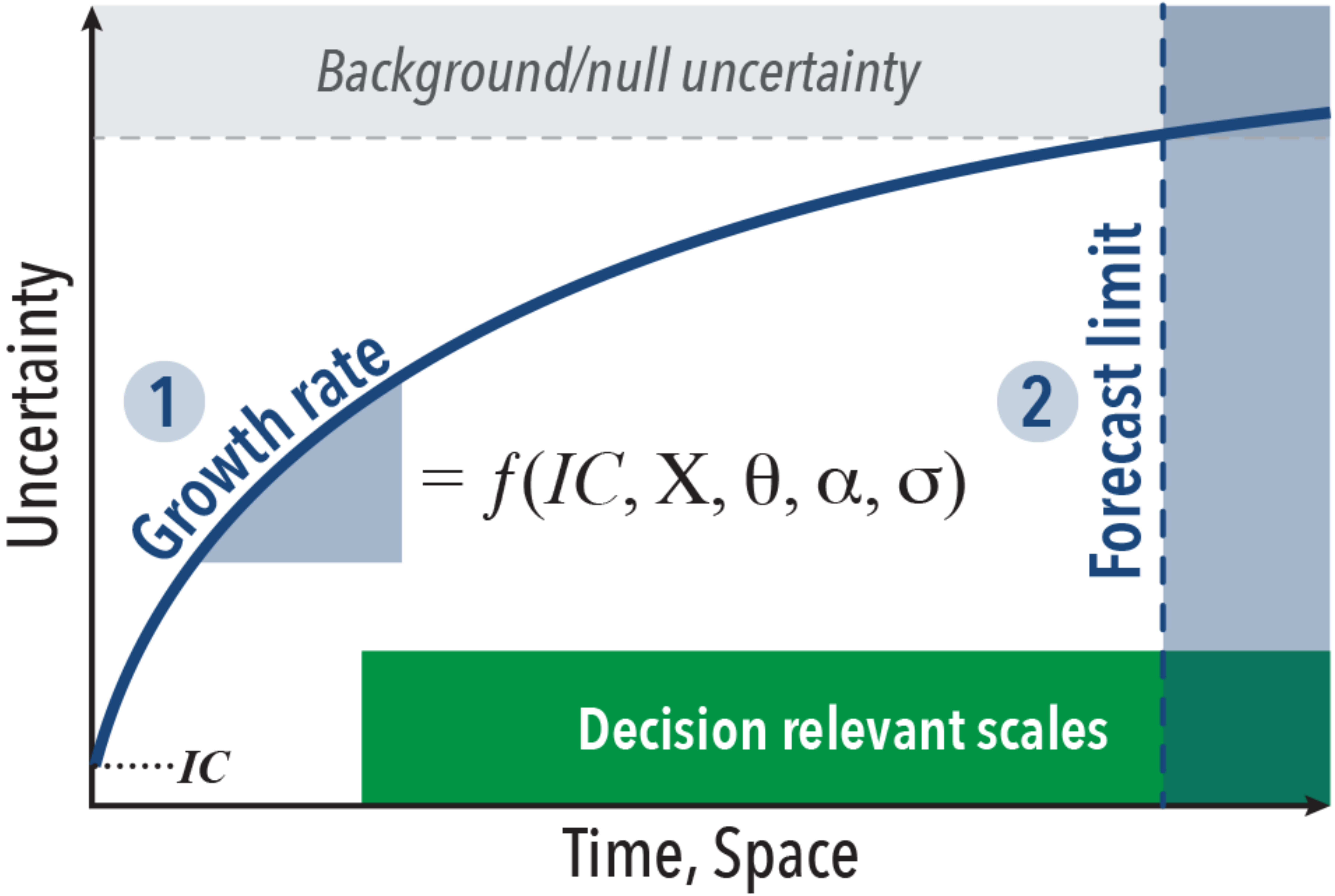
$$P(\theta|y) \propto P(y|\theta)\, P(\theta)$$

Updated State **Data** **Model**


early hardwoods
late evergreens
mid hardwoods
northern pines
late hardwoods


Characterize
Reduce
Propagate
Analyze
Mean
Median
90% CI
Aboveground Biomass (Mg/ha)
Year
1995
2000
2005
Parameter
CV (%)
Elasticity
Std deviation (g/m2)
Growth Respiration
Specific Leaf Area
Vcmax
Water Conductance
Reproductive Allocation
Leaf Allometry Intercept
Fine Root Allocation
Leaf Allometry Exponent
Stomatal Slope
Dark Respiration Rate
Quantum Efficiency
Stem Allometry Intercept
Cuticular Conductance
Root Respiration Rate
Photosynthesis Min Temp
Max Plant Height
Stem Allometry Exponent
Mortality Rate
Litter% Labile C
Seed Dispersal
Evergreen

HOW DO WE MEASURE PREDICTABILITY?

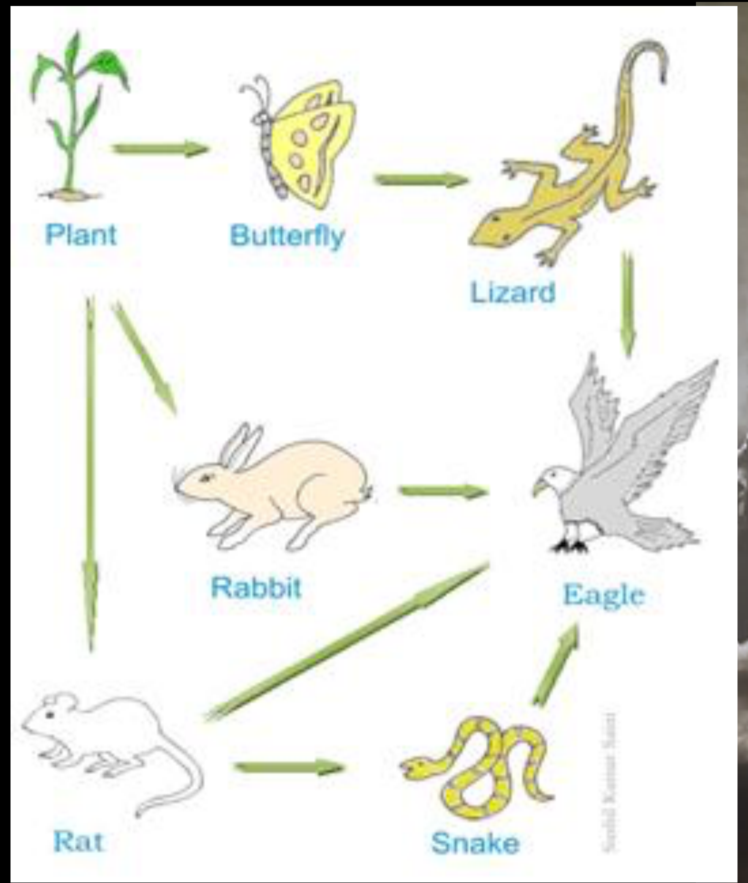


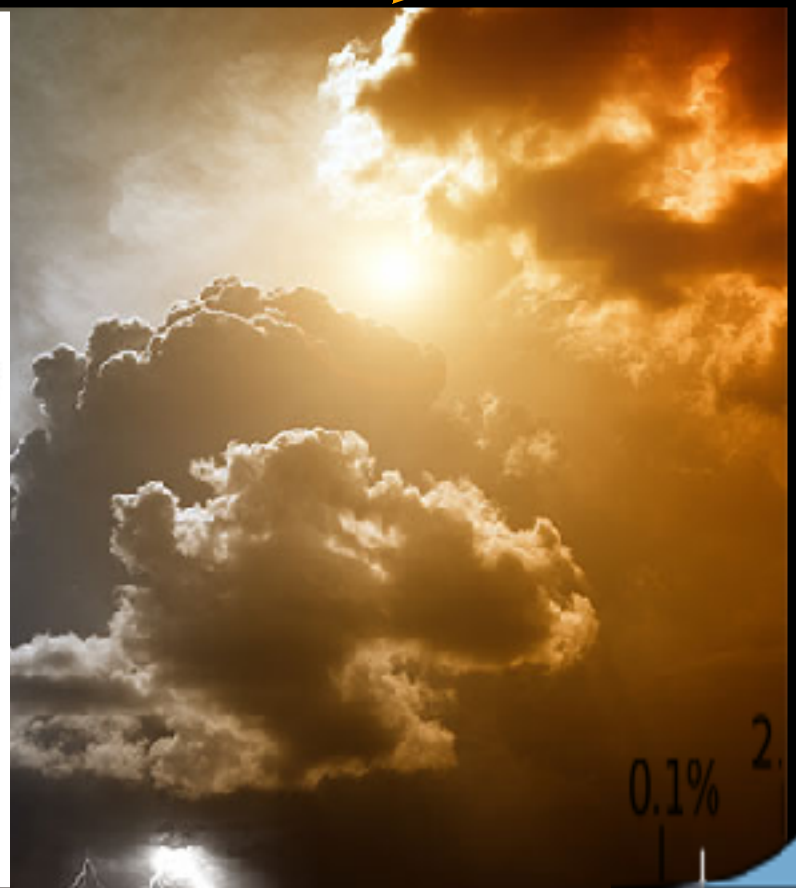
Dietze *2017 Ecological Applications*

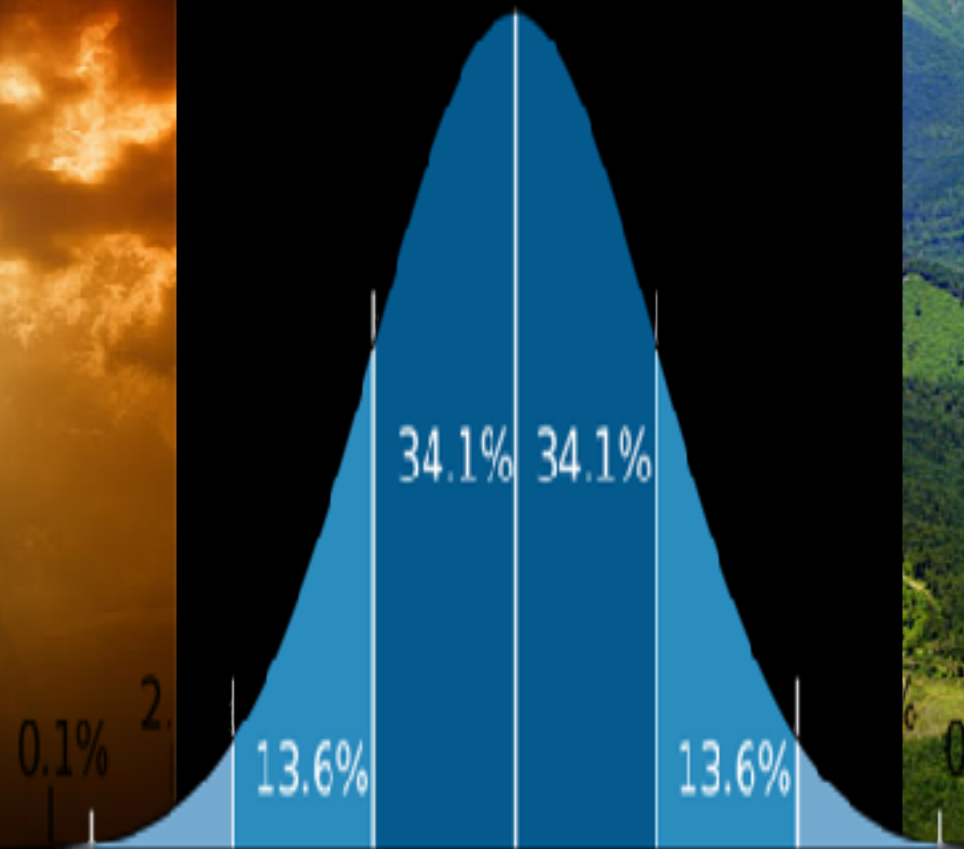
WHAT CAUSES VAR TO INCREASE WITH TIME?

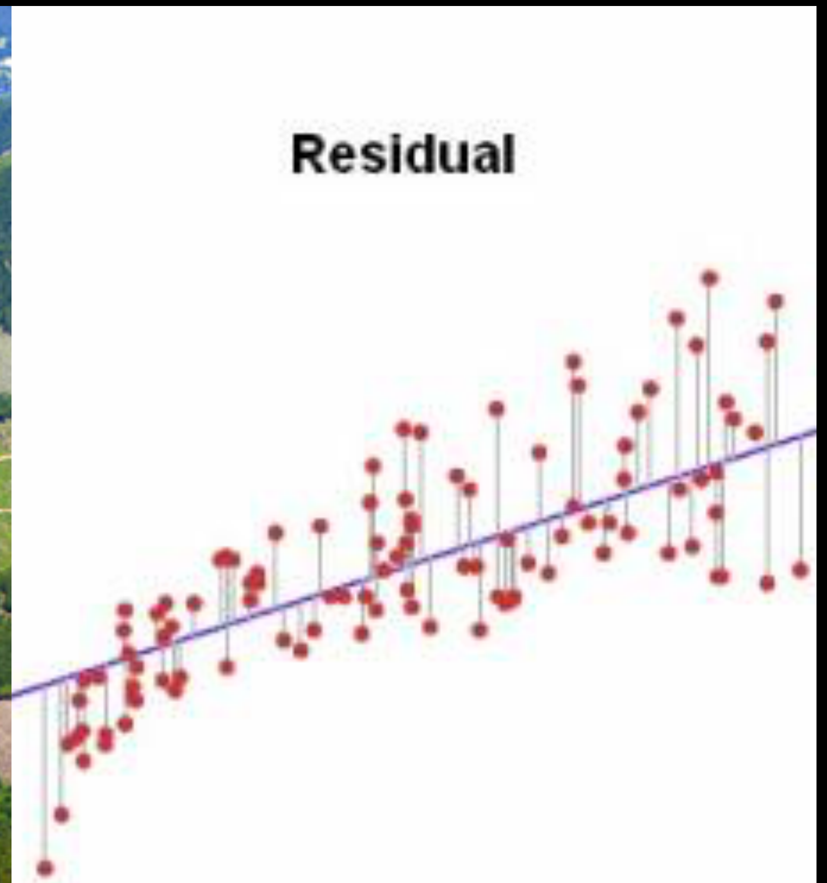
$$Var[Y_{t+1}] \approx \underbrace{\left(\frac{\partial f}{\partial Y}\right)^2}_{stability} \underbrace{Var[Y_t]}_{IC\ uncert} + \underbrace{\left(\frac{\partial f}{\partial X}\right)^2}_{driver\ sens} \underbrace{Var[X]}_{driver\ uncert} + \underbrace{\left(\frac{\partial f}{\partial \theta}\right)^2}_{param\ sens} \left(\underbrace{Var[\bar{\theta}]}_{param\ uncert} + \underbrace{Var[\alpha]}_{param\ variability} \right) + \underbrace{Var[\varepsilon]}_{process\ error}$$

$$= INTERNAL + EXTERNAL + PARAMETERS + \begin{matrix} RANDOM \\ EFFECTS \end{matrix} + \begin{matrix} PROCESS \\ ERROR \end{matrix}$$



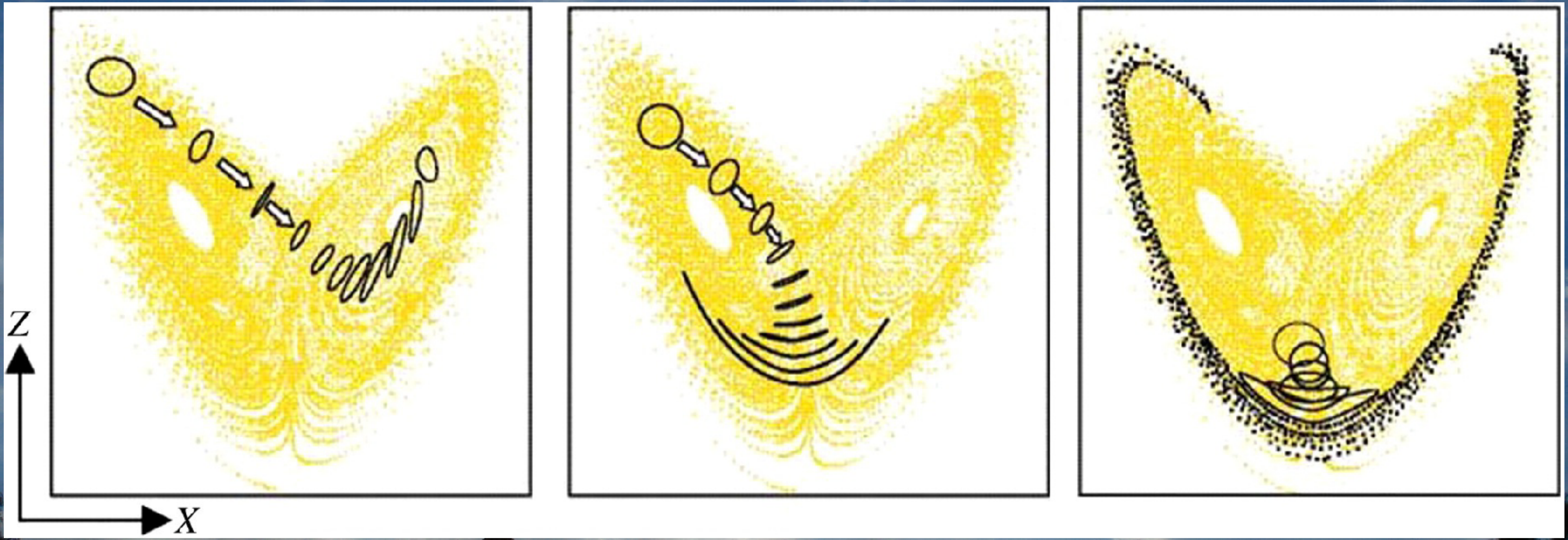






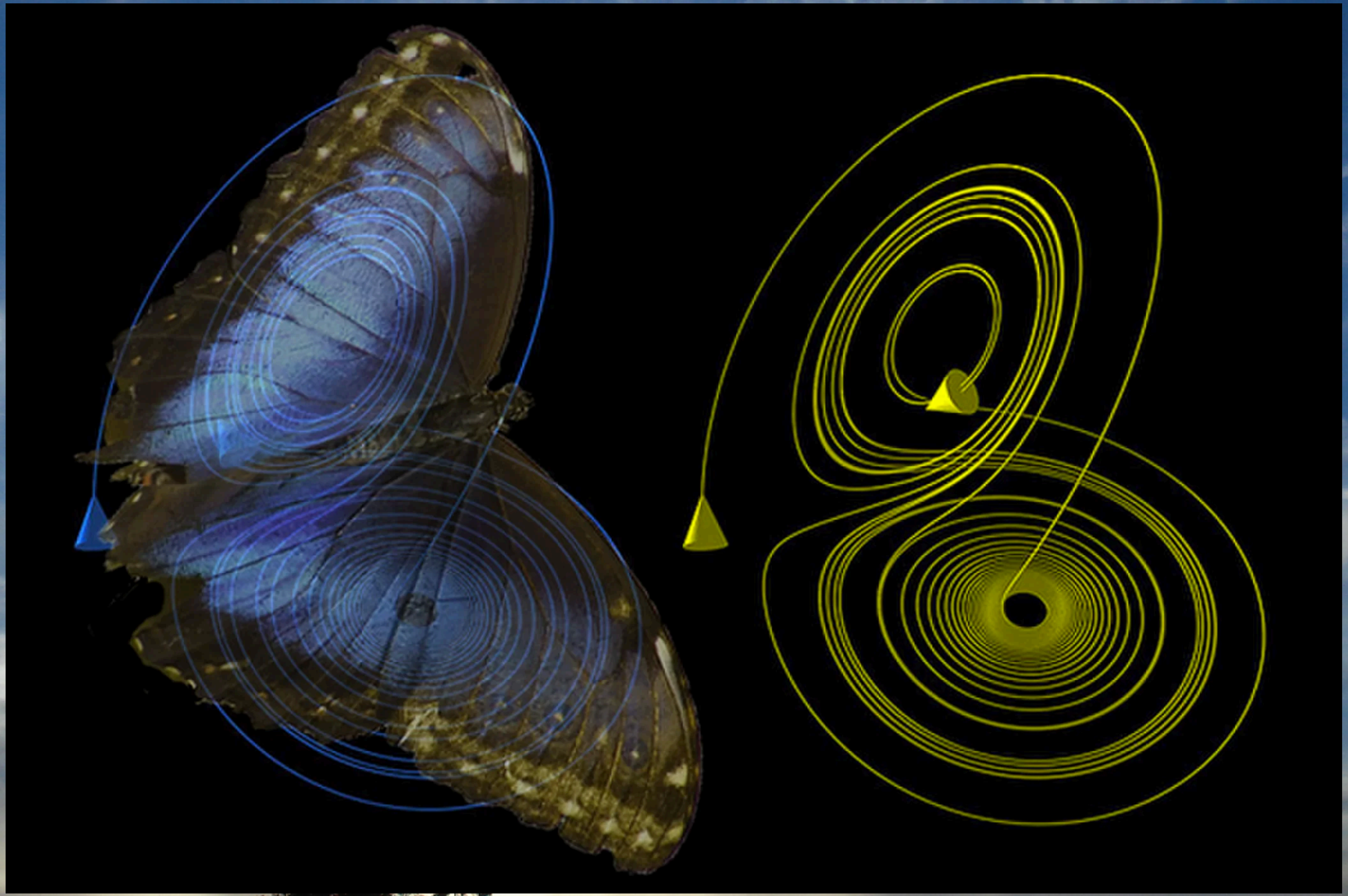
WEATHER FORECASTING:
AN INITIAL CONDITIONS PROBLEM

$$Var[Y_{t+1}] \approx \underbrace{\left(\frac{\partial f}{\partial Y}\right)^2}_{stability} \underbrace{Var[Y_t]}_{IC\ uncert} +$$



Slingo & Palmer. 2011. Phil. Trans. R. Soc. A

WEATHER FORECASTING:
AN INITIAL CONDITIONS PROBLEM



State Space ⟶ Kalman Filter

DISCOVER WHETHER NATURE IS PREDICTABLE

ECOLOGICAL FORECASTING

- Is more than forward simulation
- Requires a fusion of models and data
- Must address multiple sources of uncertainty and variability
- Think Probabilistically!!
- Needs advances in theory and methods